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Micro-remains, ENSO, and environmental reconstruction of El Paraíso, Peru, a late preceramic site

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ABSTRACT

The transition from the Middle Preceramic (8000–4500 cal BP) to the Late Preceramic Period (4450–3800 cal BP) in coastal Perú witnessed a dramatic change in both resource management and subsistence practices: lomas environments were abandoned in favor of riparian and littoral ecozones, while hunting and gathering was increasingly replaced by agriculture. The reason behind this transition remains a subject of debate; it has been attributed to population pressure, the development of domesticates, especially maize, environmental degradation or climate change. A recent regional study (Beresford-Jones et al., 2015) supports the 1960s Edward Lanning hypothesis that a combination of environmental and climate change forced Middle Preceramic occupants to move toward the river estuaries on the South Coast. Here, microbotanical data from the Late Preceramic site of El Paraíso on the Central Coast of Peru tests the Lanning hypothesis at the site-scale. The data demonstrate that inhabitants practiced a seasonal, Broad-Spectrum strategy by taking advantage of an ENSO-related florescence. Meanwhile, a trend toward increased salinity of nearby marshlands impacted the continued occupation of the site.

1. Introduction

In the 1960s through the mid-1980s, several competing hypotheses set out to address subsistence and its relationship to the origins of sociopolitical complexity in Peru. V. Gordon Childe's (Childe, 1950) Neolithic Revolution held that the domestication of staple grain crops in Mesopotamia catalyzed a fundamental change toward complex agricultural societies. In the Andes, the apparent absence of such crops, specifically maize (*Zea mays*), at the moment of emergence of such hallmarks as monumental architecture, and hierarchical organization, led to alternate explanations for the economic base of complexity. In response, though yet not evident in the archaeological record, maize was argued to have played a critical role (Cohen, 1975; Moseley, 1972; Raymond, 1981; Wilson, 1981). Michael Moseley's Maritime Hypothesis (1975) posited that the rich marine resources of the Peruvian coast provided sufficient caloric surplus to allow for the development of complex society; the increased need for cotton fish nets would encourage agricultural practices leading to a shift inland and, eventually, to irrigation agriculture (Moseley, 1975; see also Beresford-Jones et al., 2017). The overwhelming presence of malacological and fish remains at preceramic sites lent credence to this claim, though not without critique (Osborn, 1977; Raymond, 1981; Wilson, 1981). Meanwhile, others argued that there was little evidence for a linear evolution from fishing to agriculture: the Pozorskis proposed that the site of Las Haldas represented a fishing community that never adopted agriculture or moved inland, instead relying on a network of exchange for fresh water and cultigens (Pozorski and Pozorski, 2006). Recent work by Grobman et al. (2012) on the Preceramic occupations at Huaca Prieta and Paredones has pushed back the dates for early maize in the region to at least 4821–4527 cal BP through directly AMS-dated charred corn cobs (see 2012: Table 1); however the authors acknowledge that the crop was not a major food source before 4500–4200 cal BP (1759).

Early research on the Central Coast by Edward Lanning (1963, 1967) and Frederic Engel (1967, 1973), and specifically, at El Paraíso (Quilter, 1985; Quilter et al., 1991; Quilter and Stocker, 1983; Narváez, 2016) support a Broad Spectrum approach (Flannery, 1969; Zeder, 2012) to preceramic subsistence, with evidence for a variety of both domesticated and wild plants, fauna, and shell remains extracted from multiple ecological niches (see Beresford-Jones et al., 2015; Quilter and Stocker, 1983; Quilter and Stocker 1991). The well-recorded macrobotanical presence of domesticated cultigens alongside gathered wild flora in archaeological contexts at El Paraíso point to a Broad Spectrum

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strategy that includes some, though probably limited, agriculture.

Through the 1980s, many of these studies relied exclusively on macrobotanical identification of plant remains. Recent research in the on the North Coast (Piperno and Dillehay, 2008), Norte Chico region (Haas et al., 2013), in the upper Chillón Valley (Duncan, 2010; Duncan et al., 2009), Lurin Valley (Tykot et al., 2006), the southern Andes (Perry et al., 2006), and in later periods on the South Coast (Beresford-Jones et al., 2009), demonstrate the importance of complementary microbotanical evidence.

This paper provides microbotanical-based environmental reconstruction of the area around the Late Preceramic Site of El Paraíso (Fig. 1). Fourteen (14) sediment samples, originally collected by Jeffrey Quilter and the *Proyecto Bajo Valle del Chillón* in 1983, were processed and analyzed for phytolith and pollen remains. Concentrations did not warrant abundance-data analysis, therefore, presence-absence data are presented here (Fig. 3). These data are combined with two new radiocarbon dates to provide 1) the identification of a previously unknown ENSO-related lomas and marshland florescence; 2) evidence of seasonal plant management; and 3) an overall trend toward increasingly saline or brackish wetlands.

1.1. Lomas, ENSO, and coastal environmental dynamics

The coastal desert of Peru features two sources of surface water: glacial or rain-fed rivers and streams and coastal fogs, which feed 'fog oases' known as lomas (Beresford-Jones et al., 2015:198; Péfaur, 1982). During winter months (May to October), a stratus inversion layer is blown inland by trade winds and meets the steep flanks of the Andean foothills where it begins to cool and condense. The layer forms a fog, known locally as *garúa*, which supports fog-drip vegetation communities. Today, lomas typically occur between 600 and 1000 masl, though they can extend to below 300 masl. Lomas cluster between 8 and 30 ° S in Peru and Chile, in areas where steep coastal hills occur in close proximity to the coastline (Péfaur, 1982; Weberbauer, 1945[1911]). David Beresford-Jones et al. (2015) observed that Middle Preceramic sites on the South Coast often are located along watercourses that originated in lomas; moreover, evidence of water flows in the lomas themselves has been recorded (Beresford-Jones et al., 2015; Fontugne et al., 1999). Lomas support a variety of both flora and fauna,[1] and the extenuating effects on their immediate environment, such the availability of fresh water, made them potential loci for experimentation with agriculture in prehistory.

Up to 1400 plant species have been identified in the lomas of Peru and Chile from 108 different families (Dillon, 2005:135), and approximately 40% of these are endemic, indicating a long history of isolated evolution (Rundel et al., 1991:1). Beresford-Jones et al. (2015) estimates that 40% of lomas plant species are perennial and feature starchy root systems or tubers (198). Lomas plant communities include potential food sources including varieties of Solanaceae (wild potato and tomato) and *Carica candicans* (wild papaya), but also fiber (*Tillandsia*), and medicinal products (*Ephedra* sp., *Plantago*). Plants tend to cluster in altitudinal belts, with the majority of herbs located along lower terraces (300–600 masl), and large shrubs or trees occurring as altitude increases (600–900 masl). Dillon et al. (2011) list the plant families with the highest diversity at the generic or species level occurring in the Peruvian lomas (2011: Table 1)(Table 1):

Several other families are commonly found in Peruvian lomas: Begonaceae (*Begonia*), Cucurbitaceae (*Cyclanthera*), Euphorbiaceae (*Euphorbia*), Lamiaceae, Polygalaceae (*Monnina*), and Salicaceae (*Salix humboldtiana*), (see Péfaur, 1982; Rundel et al., 1991).

Table 1
Families with high diversity, and therefore endemicity or antiquity, in lomas communities (Dillon et al., 2011) and their presence in El Paraíso microremains.

Families with highest diversity at the generic level in the Peruvian lomas	
Taxa	Presence in archaeological record of El Paraíso
Bromeliaceae (Tillandsia)	Yes
Poaceae	Yes
Asteraceae	Yes
Boraginaceae	No
Brassicaceae	No
Cactaceae	No
Fabaceae	Yes
Malvaceae	Yes
Solanaceae (*Solanum*)	Yes
Calceolariceae	No
Cyperaceae (*Cyperus*)	Yes
Amaranthaceae (*Alternanthera*)	Yes
Oxalidaceae	No
Piperaceae	No
Aizoceae	No
Convulvaceae (*Ipomoea*)	Yes
Santalaceae	No

Several species are particularly sensitive proxies for lomas water availability including the genus *Tillandsia* (Dillon, 2005:132–135). According to Rundel and Dillon (1998), "nowhere in the world is the biomass of epiphytic Bromeliaceae greater than in these [Peruvian] desert habitats" (263). *Tillandsia* are epiphytic plants, having almost no root system and therefore capable of fixing on unstable surfaces such as sand dunes. *Tillandsia* is so ubiquitous in these belts during the summer and into the austral winter months that the plant communities are referred to as "tillandsiales" (Dillon, 2005; Dillon et al., 2011; Oka and Ogawa, 1984; Rundel et al., 1991; Rundel and Dillon, 1998). *Tillansidoideae* diversity and dominance in the coastal lomas areas suggest a deep evolutionary history in these environments (Rundel and Dillon, 1998). Many *Tillandsia* are slow-growing and extremely tolerant of dry periods, therefore their presence is not necessarily indicative of events such as short-term droughts. In general, however, the presence of *tillandsia* is a reliable indicator of dry, sandy conditions around herbaceaoous lomas belts, and its relative density over time may point to the expansion or contraction of lomas communities.

The Solanaceae, in particular *Nolana* and *Solanum* also demonstrate remarkable antiquity in lomas formations, with approximately 90 of the 128 species identified as endemic to these communities (Dillon, 2005:135). However, unlike *Tillandsia*, this family requires significantly more moisture for plant growth. El Niño conditions create the rare opportunity for excess moisture on the coast. El Niño Southern Oscillation or ENSO describes a climatic phenomenon that involves perturbations in normal sea surface temperatures and winds over the Pacific Ocean. ENSO has two extreme phases: El Niño, which results in heavy rains on the Peruvian coast and La Niña, which reduces precipitation on the coast. Dillon (2005) reported the affects of El Niño Southern Oscillation (ENSO) on both *Tillandsia* and Solanaceae, and determined that Solanaceae, specifically *Nolana* and *Exodeconus maritimus*, increased during ENSO years and diminished after water availability returned to normal conditions, while *Tillandsia* persisted through non-ENSO years (132). In fact, Dillon observed the cultivation of *Solanum tuberosum* in lomas during ENSO years, suggesting that the species' presence in these formations may be attributed to human activity (2005: 141).

The presence, extent and make-up of lomas formations depend on two variables: altitude and precipitation (see Péfaur, 1982); however, these variables have not held constant through time. Both short-term events, such as ENSO, and long-term change, such as eustatic sea level stabilization, have had significant and varied impacts on lomas formations. For example, Beresford-Jones et al. (2015), Dillon et al. (2011) and Manrique et al. (2010), have observed that ENSO has an overall

[1] Important animal species are known to inhabit lomas, including deer, guanaco, reptiles, birds, foxes, and importantly land snails (Beresford-Jones et al., 2015: 206–208; Craig, 1992).

Craig, A. K.
1992 Archaeological Occurrences of Andean Land Snails. *Andean Past* 3(11):127–135.

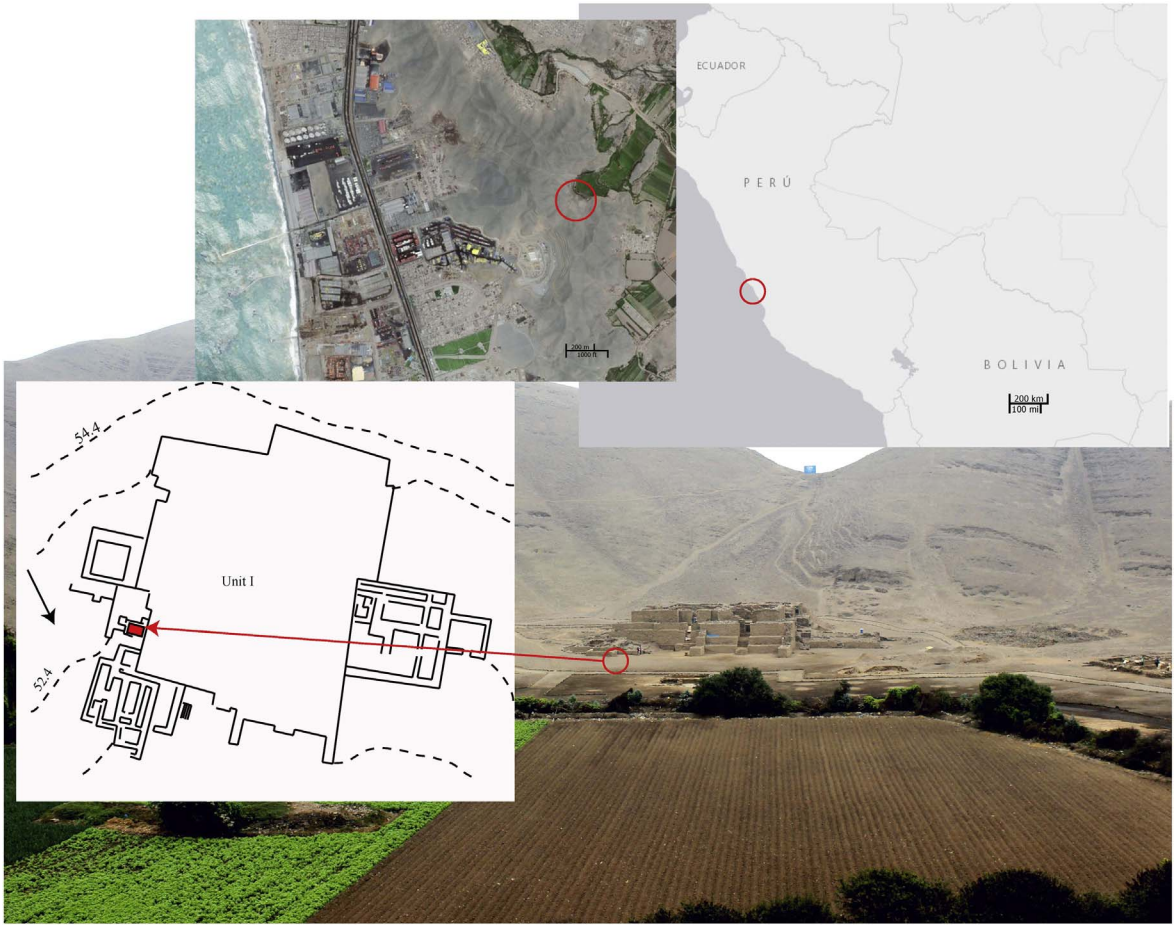

Fig. 1. Map of Unit I of the El Paraíso complex. Satellite and grayscale imagery provided by ESRI World Imagery and ESRI Light Gray Reference respectively. Plan-view map modified from Quilter (1985): Fig. 2). Photograph by Ari Caramanica of Unit I of El Paraíso taken in 2016. Arrow points to the location of Unit I Pit 2 in both the photograph and the plan-view map. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

positive effect on the extension, density (Beresford-Jones et al., 2015; Muenchow et al., 2013) and diversity (Dillon, 2005; Muenchow et al., 2013) of lomas plant species.

During ENSO cycles, lomas communities expand and rare species often appear from dormant seeds due to the abundance of water (Cano et al., 1999; Dillon et al., 2011; Manrique et al., 2010; Muenchow et al., 2013). Moreover, there is a higher degree of plant diversity and abundance, overall, with the Solanaceae, Asteraceae, and Brassicaceae families exhibiting the greatest species diversity (see Cano et al., 1999: 131; Dillon and Rundel, 1990; Muenchow et al., 2013). ENSO bolsters lomas plant communities and the history of their geographic distribution and endemic plant life is likely closely tied to the history of ENSO frequency.

ENSO frequency has varied over time. Studies drawing from sedimentary lake and marine cores (Moy et al., 2002; Rein, 2007; Rein et al., 2005; Rodbell et al., 1999), isotopic analysis of marine shell (Carré et al., 2005; Carré et al., 2014), foramnifera (Koutavas and Joanides, 2012) and corals (Cobb et al., 2013; Cobb et al., 2003), geological (Wells, 1987, 1990) and malacological (DeVries et al., 1997; Devries, 1990; Sandweiss, 1996; Sandweiss et al., 1996; Sandweiss et al., 2001) data point to two major transitions in Holocene ENSO activity.[2] It is generally accepted that ENSO activity on the Central and North Coasts (Lurín to Chira Valleys) was suppressed between 6000 and 3000 cal BP, followed by increasing frequency, peaking at 3200 cal BP and then reaching modern conditions by 3000 cal BP (for summaries see Carré et al., 2014; Sandweiss et al., 2007). Several El Niño events have been identified archaeologically for this period. At the site of Caballo Muerto in the north coast Moche Valley, Nesbitt, 2016 dates a flood-laminate layer to 3550–3400 cal BP (647), while in the Casma Valley at Huerequeque, Pozorski et al., 2016 find evidence for a major flood around the time of site abandonment circa 3350 cal BP (444). Finally, the present study produces a date of 3725-3577 cal BP for an ENSO-related plant florescence–at the site of El Paraíso. Sandweiss et al. (2001) suggest a correlation between monumental-site abandonment on the coast and the frequency of ENSO around this time, however the authors stop short of arguing causation. The relationship between human settlement and ENSO is not straightforward; however, the effects of ENSO on the local ecology, as discussed above, likely influenced site location and subsistence practices.

Sea level affects where lomas formations occur on the landscape. Today, approximately one third of lomas species are found between 600 and 900 masl, while the greatest increase in inter-seasonal plant variety occurs at 300 masl (PéFaur 1982:167–168). Lower sea levels (~35 m) during the Early Preceramic (10,000–8000 cal BP) would have resulted in lomas communities located closer to the modern-day coastline (Beresford-Jones et al., 2015; Dillon et al., 2011; Fairbanks, 1989; Richardson, 1998; Sandweiss et al., 2009). Eustatic sea levels stabilized between 7000 and 5800 cal BP, during which time early beaches were inundated (Wells and Noller, 1999). Lomas vegetation migrated upslope, likely resulting in the displacement of many Middle PreCeramic

[2] It should be noted that timing across records does not correspond exactly. These divergences may reflect different degrees of accuracy across datasets or differences in ENSO conditions across space, particularly between records from highland Ecuador (Rodbell et al., 1999; Moy et al., 2002) and coastal Peru (Sandweiss et al., 2007: 42–43; Carré et al., 2014:1046).

(8000–4500 cal BP) settlements (cf Lanning, 1963). Today's beaches are the result of progradation that began after 5000 cal BP, when eustatic sea level reached modern levels (Wells, 1996:14; Wells and Noller, 1999:775, 763).

Lomas were also vulnerable to human impact. Excavations at the Middle Preceramic site of Paloma demonstrate a marked decrease in mass of woody species at the site over time, indicating over-exploitation of nearby plant communities (Benfer, 1986; Weir and Dering, 1986). Dillon et al., 2011 support this hypothesis by arguing that woody lomas species (*Caesalpinia spinosa*, *Carica candicans*) were likely felled for firewood or animal grazing (10). Indeed, the abandonment of Middle Preceramic sites located in lomas formations may have been related to anthropogenic degradation. Archaeologists Edward P·Lanning (1963, 1967) and Frederic Engel (1973) argued that a combination of all three factors, anthropogenic, sea level and ENSO change, contributed to the abandonment of lomas environments at the end of the Middle Preceramic in favor of overlapping ecological niches and riparian environments by the end of the Late Preceramic.

Lanning (1963) first made the prescient assertion that the abandonment of lomas formations by early farmers was due to climate change, specifically a shift shoreward of the cold Humboldt Current. The movement of colder air masses over the coast would have caused the fog belt to lift and lomas formations to migrate to higher elevations (300–900 masl). Both Lanning (1963:271) and Engel (1973:360) observed that the majority of pre-agricultural sites were located in 'extinct' or 'fossil' lomas, visible thanks to preserved rootlets and snail shells, which occurred a mere 75 masl. Artifacts collected in these extinct lomas included grinding stones, milling stones, pestles and mortars, projectile points and scrapers, indicating a mixed economy of hunting, seed processing and gathering. Both Lanning and Engel pointed to the presence of cotton, beans, and later, maize, as indicators of early experiments with agriculture within lomas formations; these early experiments overlapped with a shift toward farming and fishing activities located at a distance from the lomas. Patterson and Lanning's (1964) work on settlement history in the Ancón area and greater Chillón Valley points to a large-scale movement from lomas winter camps to near-shore 'villages' around 4000–3200 cal BP (114). Ultimately, both Lanning (1963, 1967) and Engel (1973) attributed large-scale abandonment of the lomas first, to climate-related changes, including the upward migration of lomas communities and extended dry seasons, but also to increased sedentism related to farming practices, and an increasingly mixed economy reliant on riparian and marine resources. Their hypotheses have held up against the archaeological record in the Nazca and Ica region of the South Coast (Beresford-Jones et al., 2015). Lanning, Engel, and Beresford Jones et al.'s work demonstrates that lomas reached their greatest extent and their lowest altitudes during the Middle Preceramic Period and their retreat was likely in full swing during the Late Preceramic Period. Here, we test site-scale microbotanical data against this hypothesis, in an effort to trace the human-environment dynamics at the end of the Late Preceramic Period.

1.2. Overview of El Paraíso

El Paraíso is a complex of several large stone buildings located 2 km from the Pacific Ocean at the mouth of the Chillón River (Fig. 1). It is one of many sites of the Late Preceramic Period on the Central Coast, such as Caral (4600–3900 cal BP), that held religious ceremonies and supported large numbers of people both as residents or possibly pilgrims (Solis et al., 2001:725). Although these sites have been cited as examples of early "complexity" (Haas et al., 2004; Solis, 2006; Burger and Salazar-Burger, 1991), they nevertheless also exhibit signs of relatively simple social and economic systems.

The 16-radiocarbon samples collected in 1983 and analyzed shortly after produced a date range of site occupation between 4500 and 2800 cal BP (Quilter, 1985). Such dates are late for the Late Preceramic Period, possibly due to the limited excavations that took place in Quilter's investigations. It is likely that the site has older components perhaps in deeper deposits that remain to be recovered. In addition, we have dated two charred seeds, samples JQ02 and JQ10, recovered from the soil samples of the present study that confirm a late date range for Unit I Pit 2 (Table 3).

While the area around El Paraíso is under cultivation and urban sprawl today, A. Weberbauer recorded the plant communities in the area in 1910 noting the species in the coastal areas of the Lurín to Chillón Valleys (1945[1911]). Weberbauer notes lomas communities and tillandsiales to the north near Ancón, west in the Islas San Lorenzo and south of Chillón near the Río Rimac. He states that while traveling to Ancón from Chillón he observed lomas on either side of the Panamerican Highway beginning around 250 masl to 460 masl (Weberbauer (1945[1911]:258–259). However, as of 1910, Weberbauer did not report the presence of lomas, tillandsiales, or wetlands in the immediate surroundings of the El Paraíso site or the Oquendo Hills. Meanwhile, archaeological excavations by Proyecto Valle Chillón Bajo 1983 recovered macrobotanical remains that suggested Preceramic reliance on all three of these ecological areas, suggesting significant environmental transformations have taken place since that Period (Quilter, 1991).

Quilter (1985) and his team set out to establish a basic chronology and investigate the nature of subsistence at El Paraíso. Frederic Engel (1967) first excavated the site in 1965 and carried out extensive renovation of a central four-tiered structure known as Unit I, a relatively small but important structure within the site complex. Quilter expanded research into El Paraíso subsistence by targeting middens identified throughout the site.

The midden excavations suggested a diet that relied on bony fish, mollusks and limited deer and camelid, complemented by a variety of plant resources (Quilter, 1985; Quilter et al., 1991). The macrobotanical remains consisted of domesticates, including gourds (*Lagenaria siceraria*), squash (*Cucurbita ficifolia*, *C. maxima*, *C moschata*), chili pepper (*Capsicum* sp.), and cotton (*Gossypium barbadense*); cultigens such as achira (*Canna edulis*), jicama (*Pachyrrhizus tuberosus*), and beans (*Phaseoulus vulgaris*, *P. lunatus*); and managed plants, such as guava (*Psidium guajava*), lucuma (*Lucuma bifera*), and pacae (*Inga feuillei*) (Quilter et al., 1991). Wild plants, likely gathered nearby, made up a significant component of the record as well. These included grasses (Poaceae) and sedges (Cyperaceae), cattails (*Typha*), groundcherry (*Physalis* sp.), and *Solanum* spp. (1991:280). Conspicuously absent from the macrobotanical record are other known domesticates from this time period, namely maize (*Zea mays*).

Rather than dependence on either early domesticates or high protein marine resources, evidence from El Paraíso suggests its occupants exploited a variety of resources with a mixed economy following a Broad Spectrum (Flannery, 1969), or Low Level Food Production strategy (Smith, 2001). It included shellfish and bony fish, wild fauna and plants, domesticated plants, and even managed tree stands (Quilter and Stocker, 1983:554; Quilter, 1991:397). Macrobotanical data has convincingly addressed questions surrounding subsistence, however, little is known about how occupants at the site experienced seasonality, ENSO events, or environmental change. Here, we return to Quilter's 1983 excavation of Pit 2 in Unit I to address these questions through the analysis of microbotanical remains.

2. Materials and methods

The data presented here are derived from fourteen (14) soil samples collected from eight (8) stratigraphic layers of the excavation profile of Pit 2 in Unit I. Pit 2 measured 80 × 80 cm and was placed in a NE corner room of Unit I, one that was not subject to Engel's restorations (Quilter, 1985). The stratigraphy consisted of burned midden layers occasionally sealed with floors (Fig. 2). Each sample was divided for phytolith and pollen analysis, and processed following guidelines

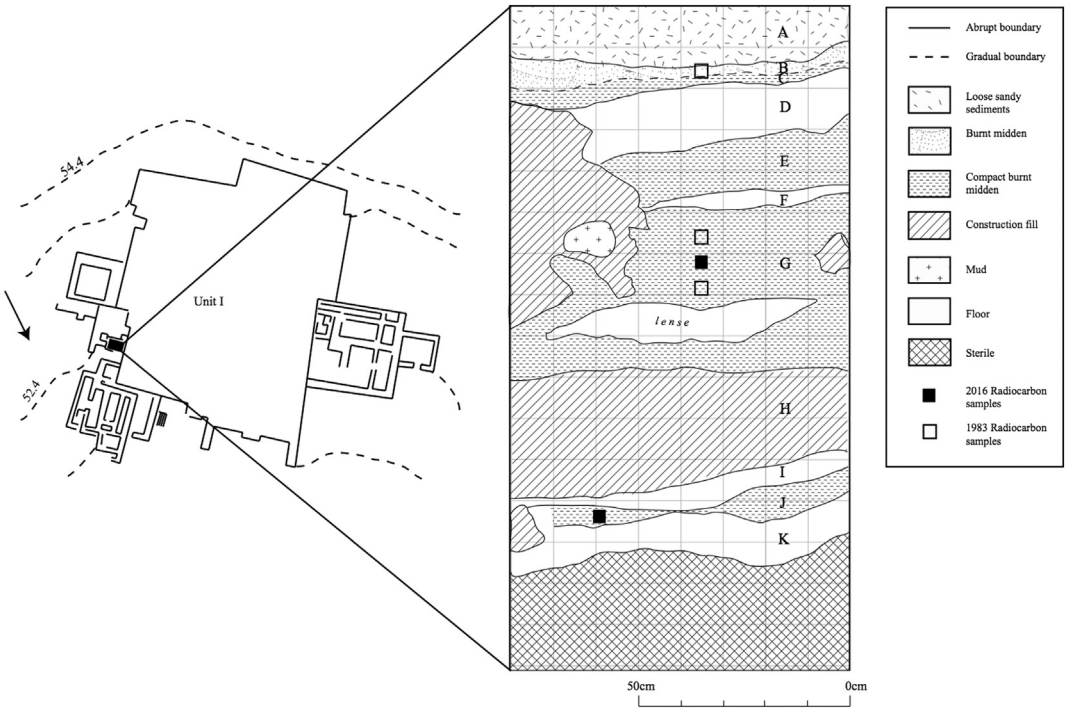

Fig. 2. Plan view of Unit I with Pit 2 indicated and excavation profile of Unit I Pit 2.

published by Horrocks (2005), Faegri and Iverson (1989), and Dimbleby (1985). These inorganic bodies are deposited into the archaeological record after plant decay, and are often found in burned or charred contexts. Under normal depositional conditions, phytoliths, which are silica bodies formed in the cells of growing plants, including epidermal cells, but also hair cells and hair bases (see Piperno, 2006), reflect the plants that were physically present in a given context. Pollen in archaeological contexts, on the other hand, can derive from a number sources. Pollen rain describes the natural dispersal of pollen grains in the open environment, particularly from anemophilous (air born pollen) species; consequently, in semi-closed or roofed structures, pollen rain is at least partially obstructed. However, pollen can also be dispersed through animal or insect transport (zoophilous) or the movement of water (hydrophilous).

Pollen samples from archaeological sites pose challenges to data analysis, but they also allow for unique opportunities. Pollen is produced in different quantities across plant families and species; this amount often depends on the type of pollen transport (Faegri and Iverson, 1989). For example, while zoophilous plants, such as the genus *Acer*, produce around 1000 grains per anther, anemophilous species, including many trees, produce pollen in much higher numbers, approximately 10,000 grains per anther (14–15). In a lake-core, the pollen record reflects continuous deposition of pollen rain from the catchment area. Similarly, archaeological contexts may contain microfossils from all types of plants—managed or otherwise—however, within archaeological contexts pollen deposition is often episodic (Mercuri et al., 2010:888). The archaeological record provides spatial and anthropogenic data that are typically absent from environmental samples (Hjelle et al., 2012:1368). In Unit I Pit 2, the pollen record reflects a combination of human-plant activity, the surrounding environment, and taphonomic processes (Fig. 3).

Together, pollen and phytolith data provide information on in situ plants (phytoliths), in this case moved into the NE corner room through human activity, and plants living in the nearby environment (pollen catchment area). Phytoliths typically represent the presence of a plant part in a given context—the micro-remains of a leaf, stalk, seed or hair that was present in Pit 2. Meanwhile, pollen grains most often enter the archaeological record through the forms of transport described above. Comparing phytolith with pollen records allows the researcher to check for inconsistencies across results. In the case of Pit 2, while the degree of taxonomic classification varies, all phytoliths, including rare phytoliths such as *Heliconia*, are accounted for in the pollen record and vice versa. The high degree of correspondence across the pollen and phytolith results suggests that many of the plants growing in the vicinity of El Paraíso, were eventually brought into Unit I Pit 2—representing in situ human-plant activity.

3. Results

The pollen and phytolith records presented here point to three central postulates: first, an important plant florescence occurred around 3700–3600 cal BP (see Tables 2 and 3); second, rare, moisture-dependent plants indicate seasonal subsistence strategies, and third, in later levels, lomas and marshland contract, become increasingly saline, and these plants communities are largely replaced by important cultigens and disturbed-soil-preferring species (Fig. 3).

Due to an overall low concentration of pollen grains and the possibility of depositional bias, the results presented here reflect the presence or absence of a given taxa per level in Pit 2 at El Paraíso. Presence-absence data express taxa richness (S) per level, a measure of diversity (see Koleff et al., 2003). Here, we suggest that a sudden increase in diversity is suggestive of ENSO-related florescence (see Muenchow et al., 2013), or 'blooming event' around 3700–3600 cal BP (Tables 2 and 3).

3.1. ENSO-related florescence

High diversity scores might result from an increase in plant material, and therefore would be accompanied by an increase in phytolith material. Meanwhile, Level G, and surrounding Levels H and J have the lowest phytolith concentrations, but all three levels have high pollen concentrations, suggesting the pattern presented in Table 2 reflects real plant diversity in the environment and in Unit I. While radiocarbon samples acquired during the 1983 Project express a date range of 4500–2800 cal BP for Level G, the present study prefers to rely on the two newly acquired radiocarbon samples, JQ10 and JQ02, for the dates

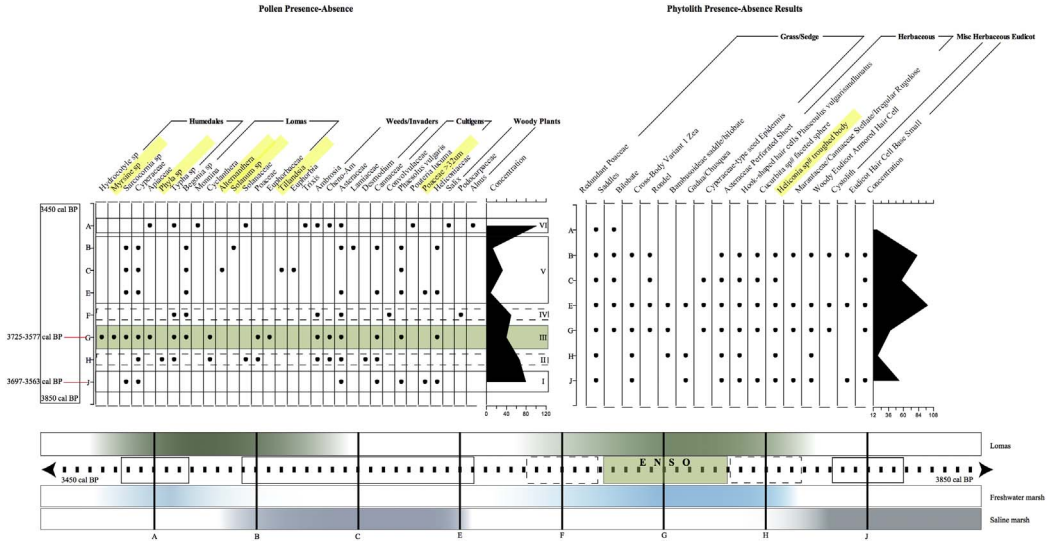

Fig. 3. Presence-Absence pollen (left) and phytolith (right) profiles extracted from sediment samples from Unit I Pit 2 at El Paraíso. Radiocarbon dates are indicated (left). Pollen data are grouped into six paleo-phases, indicated by solid or rectangular bands. See Appendix A for principal component analysis that supports groupings. Phases II and IV are classified as transitional phases. Blooming event in Level G is highlighted in light green band. Timeline (below) indicates stratigraphic levels and the relative density of lomas vegetative communities, and freshwater and salt-tolerant marsh plants. Blooming event is represented with a light green band labeled ENSO. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of Level G. The 1983 samples were derived from wood charcoal, leaving open the possibility of an 'old wood' problem (see Schiffer, 1986). In contrast, JQ10 and JQ02 were taken from charred seeds, providing a more accurate age range (see Table 3). According to these new dates, Level G can be dated to 3700–3600 cal BP and demonstrates the highest degree of species diversity (Figs. 2 and 3). Pollen in Level G derives largely from lomas species, including the tuberous flowering plant *Begonia*, and marsh species, such as *Typha* or cattail—plants that thrive under conditions of increased moisture or presence of water (Fig. 3).

ENSO events result in greater species diversity and the appearance of several Solanaceae species such as *Nolana* and *Exodeconus maritimus*, and El Niño flooding leads to the expansion of marshes and wetlands (Carré et al., 2014; Dillon, 2005; Manrique et al., 2010). Level G has the highest degree of species diversity, including wetland and marsh plants, lomas plants, and the presence of a rare, typically Amazonian, plant family for this region, Heliconiaceae, which presents as the species *Heliconia* in the phytolith assemblage. Meanwhile, Solanaceae appears in the previous Level H. Though the taxonomic precision from these pollen grains does not allow for the identification of *Nolana* or *E. maritimus*, the presence of *Solanum* points to increased water availability and possibly to ENSO-related human activity (Dillon, 2005). Together these variables strongly point to an ENSO-related plant

Table 2
Line graph representing relative species richness (S) in each level of the Unit I Pit 2 excavation. Level G presents an unusual degree of species richness pointing to a moment of florescence.

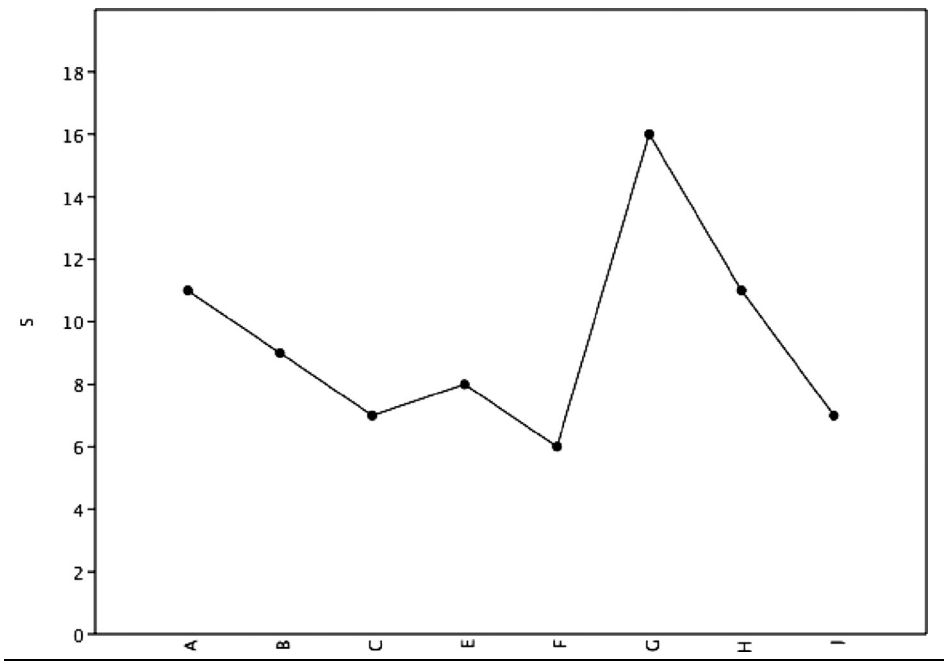

Table 3
Radiocarbon dates from excavations at the site of El Paraíso. Asterisks and bold type indicate the most recently processed radiocarbon samples, two charred seeds. New dates were processed by Keck Carbon Cycles AMS Facility. All samples with the prefix I-13 were originally analyzed by Teledyne Isotopes for publication in Quilter, 1985; all samples with prefixes I- or P- were originally published in Engel, 1967; Beta-9704 and 8703 were analyzed by Beta Analytic for publication in Quilter, 1985. All dates were re-calibrated using the *SHCal13 Curve (Hogg et al., 2013) in Oxcal 4.3 (Bronk Ramsey, 1995, 2009; Bronk Ramsey, 2013). *The calibrated age range is at 95.4% confidence.

El Paraíso radiocarbon dates						
Reference No.	Provenience	Sample No.	^{14}C yr BP	Age cal BP	Age cal BC 95.4% Confidence	Sample description
1	Unit I, Pit 2, Level B	I-13, 276	3560 ± 100	4091–3561	2141–1611	Wood charcoal from midden
2	Unit I, Pit 2, Level G	I-13, 275	3550 ± 100	4086–3516	2136–1566	Wood charcoal from midden
3	Unit I, Pit 2, Level G	Beta-8704	3020 ± 60	3344–2965	1394–1015	Wood charcoal from midden
4	**Unit I, Pit 2, Level G***	**JQ10**	**3455 ± 20**	**3818–3797** **3725–3577**	**1868–1847 (3.1%)** **1775–1627 (92.3%)**	Charred seed
6	**Unit I, Pit 2, Level J***	**JQ02**	**3420 ± 20**	**3697–3563**	**1747–1613**	Charred seed
7	Unit I	I-1676	3570 ± 150	4241–3450	2291–1500	Cinders found on stairs
8	Unit I	P-1214	3444 ± 59	3832–3484	1882–1534	see Engel, 1967
9	Unit I	P-1210	3666 ± 59	4146–3727	2196–1777	see Engel, 1967
10	Unit I	P-1209	3065 ± 61	3375–3007	1425–1057	see Engel, 1967
11	Unit IV, Pit 1, Level C	I-13, 274	3790 ± 100	4434–3896	2484–1946	Wood charcoal from midden
12	Unit IV, Pit 3	I-13, 278	3650 ± 100	4285–3695	2335–1745	Reed fragment from bag used in fill
13	Unit IV, Pit 3	Beta-8703	3170 ± 150	3818–2970	1868–1020	Reed fragment from bag used in fill
14	Unit II, Pit 4, Level C	I-13, 277	3370 ± 100	3861–3391	1911–1441	Wood carbon from hearth
15	Unit II, Pit 4, Level O	I-13, 503	3420 ± 90	3896–3456	1946–1506	Wood charcoal from midden
16	Unit II, Pit 6, Room 1	I-13, 504	3470 ± 90	3910–3456	1960–1506	Wood charcoal from feature no. 1
17	Unit II, Pit 6, Room 1	I-13, 505	3310 ± 90	3809–3253	1859–1303	Wood charcoal found on Floor 3
18	Unit II, Room 2 W, Level D	I-13, 506	3520 ± 90	4081–3576	2131–1626	Wood charcoal from midden
19	Unit II, Room 2 W, Level F	I-13, 531	3520 ± 240	4515–3240	2567–1290	Wood charcoal from midden

florescence.

Heliconia, a member of the bird-of-paradise family Heliconiaceae, is an understory herb whose range is restricted to the eastern slopes of the Andes, the Amazon lowlands, and the northern cloud forests of Peru.[3] With the exception of two archaeological examples, including the El Paraíso evidence, *Heliconia* is not known on the western slopes of the Andes (see Duncan, 2010). *Heliconia* is a flowering plant that features large leaves, often compared to banana leaves. Neil Duncan (2010) completed his Ph.D. thesis on the phytolith and macrobotanical material collected from the Late Preceramic site of Buena Vista, located in the upper Chillón Valley. There, he recorded *Heliconia* phytoliths in burned contexts (2010: 245–250). Duncan acknowledges the possibility that *Heliconia* was being grown on the coast at the time, but suggests that the plant arrived to the site from elsewhere as a food wrapping, akin to cornhusks for tamales (245, 251). At El Paraíso, the presence of both phytoliths and pollen of the plant signals that *Heliconia* was in fact growing nearby and being used by site occupants.

Finally, the identification of an ENSO beginning perhaps in Level H and continuing through Level G, is in agreement with Sandweiss' (1996) analysis of the malacological remains recovered from Pit 2 in 1983. *Mesodesma donacium*, a sand-dwelling wedge clam, is devastated or disappears entirely during strong El Niño events (Sandweiss, 1996:137). Sandweiss identified two possible ENSOs based on the dramatic dip in relative weight of *Mesodesma donacium* in Levels H and C in Pit 2 (139). While plant-growth often begins slightly after El Niño effects manifest, these sensitive clams likely began dying as soon as sea temperatures began to rise in Level H.

3.2. Seasonality

The presence of *Heliconia* on the coast points to substantially different environmental conditions during the Late Preceramic Period (see also Piperno, 2006:137). Moreover, in each level where *Heliconia* is present as a phytolith, it is also present as a pollen grain, and vice versa. Both phytoliths and pollen correspond perfectly in the case of this species, appearing in every-other level tested. *Heliconia*, therefore, acts as a sensitive proxy for seasonality: indicative of austral summers—i.e. the off-season for lomas under normal, non-ENSO conditions. This would suggest that the excavation profile represents at least four summers in Levels J, G, E and B. The stratigraphic relationship of the layers suggest four sequential years, although without more extensive radiocarbon dating, the time intervals between each 'season' cannot yet be confirmed (Fig. 2). Still, in what would be the winter-month levels (Level H, F, C and A), lomas plants are present and disturbed-soil or cultigen species predominate—possibly reflecting wintertime gathering in blooming lomas, gardening and some agriculture (see Fig. 3).

Level C pollen represents further evidence of marked seasons at El Paraíso. Level C presents evidence for a non-ENSO year—resulting in negative effects for lomas environments (Beresford-Jones et al., 2015: 210; Dillon, 2005). Overall, Level C shows evidence for impoverished marsh and lomas plant life across phytolith and pollen records, while the presence of *Tillandsia*, and *Euphorbia* in the pollen record indicates the expansion of sandy, loose soils typically found at the margins of lomas communities during summer months or non-ENSO years (Rundel and Dillon, 1998). Furthermore, pollen and phytolith concentration in this Level is relatively low suggesting a dip in human-plant activity overall at the Site.

3.3. Evidence for increasingly brackish wetlands

Freshwater or estuarine marsh and wetland species, especially *Phyla* and *Typha* are present in the lowest levels of Pit 2 (Levels J, H, and G) (Leon and Young, 1996). The severe drop in wetland and lomas species in Level F suggests site abandonment or the razing of marsh and lomas resources; at the same time, disturbance species are slightly more abundant. The microbotanical data suggest a seasonal influx of freshwater, probably tied to the summer increase in river discharge and runoff. Over time, however, marsh species generally diminish and freshwater plants give way to salt-tolerant plants, represented in the pollen record as *Sarcocornia* and Cyperaceae in Levels E, C and B. It is possible that the observed patterns are the result of human management, given that both *Sarcocornia* and Cyperaceae have starchy rhizomes that can be collected as a food resource. However, the pollen record in Pit 2 suggests a gradual drying out of these environments over time and the replacement of freshwater cattails with salt-tolerant plants in the surviving marshes (see Fig. 3). Further study, particularly of

[3] *Heliconia* L. is also found in Melanesia (Iles et al., 2017).

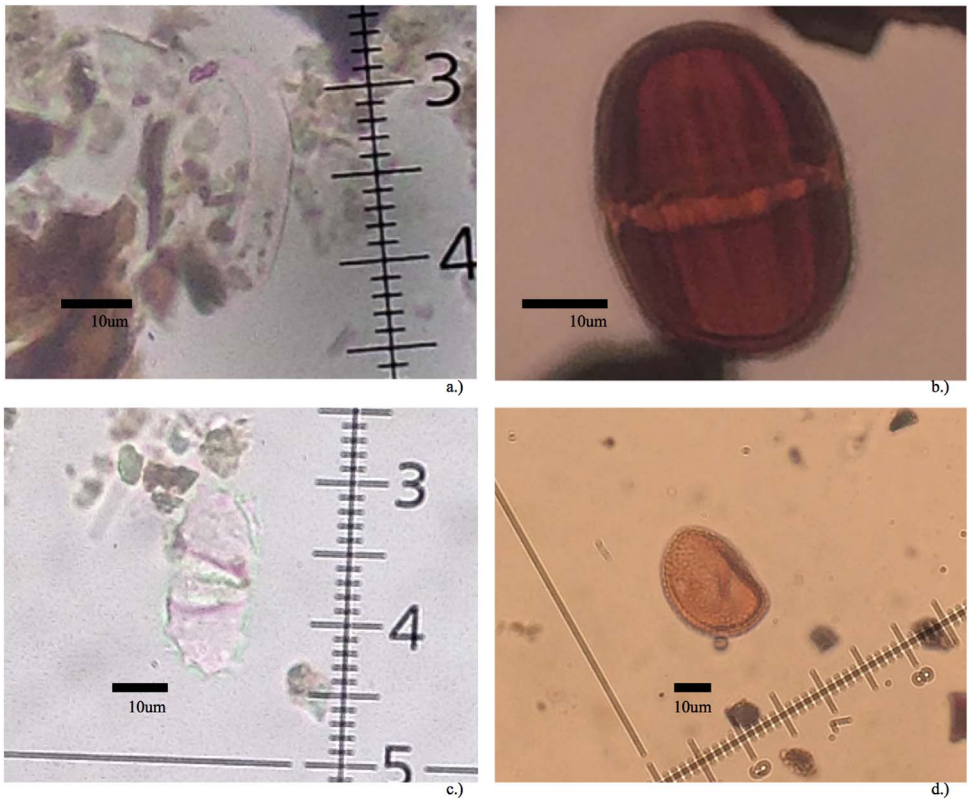

Fig. 4. Images of pollen grains and phytoliths extracted from the 1983 El Paraíso sediment samples. a.) Phytolith identified as hair cell from *Phaseolus vulgaris* L. (common bean); b.) Pollen grain identified as *Monnina* sp.; c.) Phytolith identified as *Heliconia* sp.; d.) Pollen grain identified as *Typha* sp. (cattail).

mollusk remains from El Paraíso, may shed light on the processes, erosive, climatic, sea-level rise, or anthropogenic (see Leon and Young, 1996:1180–1181), which lead to this shift.

Marked change in wetland ecozones would have had profound effects on plant management practices at El Paraíso. The pollen and phytolith records suggest that residents responded with an increased reliance on cultigens. Phytoliths from important domesticates, such as maize (*Zea mays*), common beans (*Phaesolus vulgaris)* and squash (*Cucurbita*), appear together beginning in Level G, identified as an ENSO florescence, but persist through levels E, C, and B while other taxa disappear. Pollen for *Phaesolus vulgaris* and Poaceae (> 32 μm), likely from maize (*Zea mays*), are present in Level E, corroborating the phytolith data—confirming that maize agriculture was under way at this time, though its cultivation did not lead immediately to complex irrigation organization (see also Burger and van der Merwe, 1990).[4] The microbotanical evidence suggests that as wetlands and lomas diminished or became increasingly saline domesticates and cultigens predominated (Fig. 4).

As discussed earlier, the topic of early maize in the Andes continues to be an active debate, and the coincidence in the present study of important cultigens, such as *Zea mays*, with disturbance species, including *Heliconia*, which Piperno, 2006 describes as “an early pioneer that quickly invades the edges of human clearings and large, natural forest gaps (137)”, suggests that land was being turned over for cultivation toward the end the Pit 2 sequence. It is possible that as wetland ecozones dried out, farmers focused their efforts on water transport through irrigation canals, or relocated fields closer to the Chillón River as a freshwater resource. Finally, the very wetlands that were drying out could have been converted for field use; however, these hypotheses require further investigation.

[4] *Cucurbita* pollen is not common, rather starch or phytolith data would be more illustrative (Piperno, 2006:Table 1.1; Duncan et al., 2009).

4. Future research

The results from our analysis express a high degree of concordance between phytolith, pollen and macrofossil records from El Paraíso. One important exception is related to the issue of maize. No macrofossil remains were recovered from the site in the course of the 1983 Project. The current archaeological project being carried by José Joaquín Narváez Luna and the Ministry of Culture have recovered multiple macro-botanical remains, including several corn cobs, from excavation in a sector of the site designated as *Sector de servicios multiples* or the “Multiple Services Sector” located about 200 m north of Unit I and only about 40 m from later components of the Site complex (Narváez, 2016:22). In collaboration with the Harvard Peabody Museum, several of these corn cobs are currently being dated. In any case, Unit I seems to have been completely cleaned of any macro-maize remains, highlighting the importance of micro-remain analysis for future studies.

5. Conclusions

Archaeological contexts are often imperfect samples for uninterrupted environmental reconstruction but they do provide a rare window into human-plant dynamics within a specific space and time scale. The samples extracted from Quilter's 1983 Unit I Pit 2 excavation speak to three central elements of the Late Preceramic Chillón environment. First, the site of El Paraíso was located near marshlands, as aquatic and wetland species are numerous in early layers of the site. Lomas, the fog-drip communities crucial for Middle Preceramic subsistence, had not yet disappeared. In 1911, Lomas are reported by Weberbauer in the nearby Ancón and Rímac valleys and San Lorenzo Islands, but no lomas communities are recorded in the immediate surroundings of the Site (see Weberbauer, 1945[1911]). However, pollen evidence shows that they were present throughout the occupational sequence of Unit I Pit 2 at El Paraíso, which we can confidently date to at least as early as 3700 cal BP (Table 3). Both lomas and marshlands are extremely sensitive to seasonal fluctuations that affect the

availability of water. Moreover, sometime around 3700–3600 cal BP, a major blooming period occurred. The diversity of species, particularly lomas plants, and the evidence of a moment of marsh- and wetlands expansion recorded at this time, all point to an ENSO-related blooming period. Indeed, major El Niño events, while often destructive, have been shown to have positive effects on lomas environments, and indirectly, result in sources of fresh surface water (see Fontugne et al., 1999). Finally, the presence of *Heliconia* in four of the eight recorded-layers suggests that Site occupants were actively exploiting summer growth.

Perhaps the most significant trend for El Paraíso subsistence was the gradual shift toward shrinking and increasingly saline wetlands. In response to the disappearance of important aquatic species such as *Typha* (cattail), and dependent fauna, El Paraíso's occupants invested further in farming. Plants that prefer disturbed or tilled soil and cultigens began to replace the lomas and wetland species.

By combining regional studies (Beresford-Jones et al., 2015; Lanning, 1963, 1967) with site-scale environmental reconstruction, details of human-environment dynamics of the Late Preceramic period come to light. Despite the long-argued paradox of achieving complex society in the absence of a staple grain crop (see Raymond, 1981; Wilson, 1981), the monumental site of El Paraíso was planned and positioned in order to exploit multiple, overlapping ecozones (Quilter, 1991; Quilter et al., 1991; Quilter and Stocker, 1983). Moreover, despite the often negative effects of ENSO, El Paraíso residents took advantage of seasonal florescence and a major ENSO-related blooming period around 3700–3600 cal BP. Ultimately, Lanning's (1963) prescient prediction that preceramic hunter-gatherers found themselves in an increasingly changed environment due to the stabilization of both sea levels and ENSO patterns holds true in the South Coast (Beresford-Jones et al., 2015), and now also in the Central Coast. El Paraíso adds to this narrative, by highlighting the continued practice of seasonal opportunism and Broad Spectrum resource exploitation, and the significance of disappearing marshland environments. Finally, we have identified the presence of maize at the site, though it apparently was not a major component of the diet at El Paraíso. In this way, Late Preceramic societies, while poised to take on large-scale irrigation agriculture, continued to carry out opportunistic strategies.

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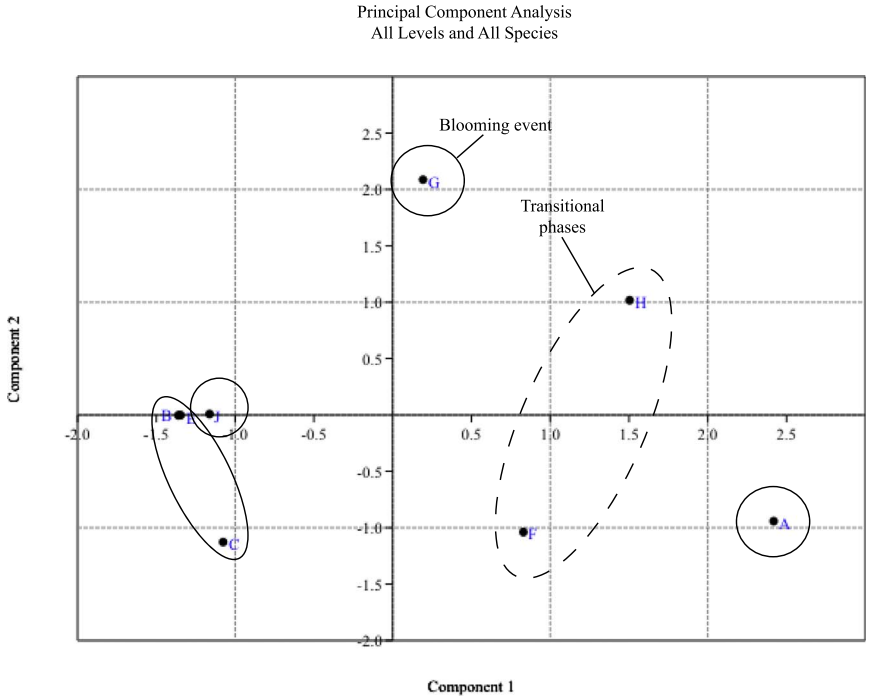
Appendix A



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